Exploratory Design of Animal Habitats Within an Immersive Virtual Environment

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ABSTRACT

One of the first useful applications of virtual environments (VEs) was the architectural walkthrough, in which users view buildings or other structures in a natural, interactive manner. The obvious next step is to allow the user to create or modify designs while immersed in the virtual world, but such "immersive design" systems have not generally been successful, because of a lack of constraints, the inability to perform precise input, the difficulty of performing complex tasks while immersed, and the fact that designers generally have not been trained to design in all three dimensions, especially in the beginning stages of a project. We present an immersive design application, aimed at university-level architecture students, which addresses these issues. Users of the system are immersed within an existing zoo habitat, and can make modifications and enhancements to the exhibit, using a set of efficient and complementary interaction techniques for navigation, object manipulation, and system control. A usability study has shown that because the students are not creating a complete design, but rather making constrained modifications to an existing one, interesting and unique designs can be achieved in a short time.

INTRODUCTION

Immersive virtual environments (VEs) present a unique experience to the user. This experience is characterized by a three-dimensional (3D) display, interactive view specification using head-tracking, and an ego-referenced, or inside-out, point of view. These qualities make VEs extremely useful for the visualization of 3D spaces, since the user can be immersed within the space and view it as if he were actually there.

Because of this, the architectural walkthrough became one of the earliest applications of VEs, and is still the canonical example of a VE system that has made an impact outside the research laboratory. In an architectural walkthrough, the user is placed within a 3D model of a building or other architectural design, and can move through the space to view it from any location and viewing angle. Because viewing is dynamic and interactive, this is a very effective way for users to understand the layout, scale, and aesthetic qualities of the architectural space.

But what is the purpose of a walkthrough? If the building is already complete, an architectural walkthrough may allow people who cannot visit the actual location of the building to see what it looks like. More often, however, walkthroughs are used to evaluate or verify a design which is under consideration, or which is only partially complete. In most cases, then, the user will suggest modifications to the design as a result of what she saw in the walkthrough. With a standard walkthrough, the user must leave the virtual space, then changes to the design must be made using desktop computer-aided design (CAD) tools, and the new design must be saved in a format that is usable by the VE system. Finally, a new walkthrough can take place, which may spur another round of modifications. This leads us to a question: if the user, while immersed in the space, can propose changes that need to be made, why can she not effect those changes immediately, so that the results are immediately visible?

This is precisely the idea of "immersive design." Users of an immersive design application can not only interactively view the space, but can also make changes to the position, orientation, scale, shape, color, or texture of features within the design. Moreover, since the tools allow modification of existing objects, such applications generally also allow the creation of new objects or even complete designs from scratch. With a usable immersive design system, the design process should become much more efficient and satisfying.

Unfortunately, there are several problems which plague most virtual design environments. First, the task is not well-constrained. There are a huge number of possible actions that the user might want to perform (just look at the complexity of most 2D or 3D CAD systems). In an immersive design system using a head-mounted display (HMD), the user must perform these actions with a low-resolution, narrow field of view (FOV) display, and using unfamiliar input devices. To make matters worse, the user may be specifying six degrees of freedom (DOFs) simultaneously (three positional and three rotational). This allows great freedom and flexibility, but is too much for most users to handle. Second, design often requires precise input, which is inherently difficult in immersive VEs, since the standard text and numeric keyboards are missing. Rather, input is often done with a 3D device such as a tracker, and perhaps with a limited number of buttons. Finally, designers are simply not accustomed to creating designs or even making changes in a three-dimensional space. Design concepts are usually sketches on a piece of paper, and even if a computer is used, the early stages of design are almost always 2D, with 3D only being used for presentation or tweaking near the end of the process. This is perhaps the most devastating problem for immersive design, because the concept will never work until designers are willing to think in a new way.

In this paper, we present an immersive design application that takes a different approach. First, we focus on the small, highly-specific domain of animal habitat design. Second, users of the system are not presented with a blank slate; rather, they begin with an existing habitat (the gorilla habitat at Zoo Atlanta). Finally, the design tools do not allow general manipulation of all the aspects of the exhibit. Instead, they are highly task-specific and well-constrained. Users must focus on certain design features and choose between a small set of options for those features. The options are based on principles of good habitat design, so that even though flexibility is limited, interesting and unique designs can still be created. This application is geared towards university-level architecture students who are learning about environmental design. We feel, however, that the principles embodied in this system can be extended to applications of immersive design in other architectural domains.

In the next section, we will discuss previous research in immersive design. We will then discuss our application, and present a usability study in which students in an environmental design class used the system to perform a design project. We will conclude with some discussion and ideas for future work in this area.

RELATED WORK

Design has long been considered a fertile application category for 3D computer graphics systems, including immersive virtual environments. Desktop applications that present 3D views in a window for the purposes of design are now quite popular, and are widely used in industrial and professional settings. Immersive design systems, on the other hand, have generally existed only as research prototypes.

An early example of an immersive modeling tool is the 3DM system [1], which allowed the user to build objects with various combinations and sizes of primitive objects. Mine's work extended these ideas to give the user more flexibility, better control over position, orientation, and scale, and many different modes of interaction. His ISAAC [2] system is characterized by the use of constraints, easy-to-use widgets for object interaction, and a centralized menu system which gives users control over every aspect of the system.

Our own experience with the Conceptual Design Space (CDS) system [3] gave us insight into some of the problems of immersive design. In CDS, as in ISAAC and other systems, users could create primitive objects and combine and transform them; they could include models from desktop CAD systems; they could add aesthetic properties such as color and texture; and they could save designs to a format readable by desktop 3D applications. CDS made use of a virtual menu system and a consistent interaction metaphor.

As its name suggests, the goal of CDS was to allow designers to conceptualize a design before refining it using a more robust desktop application. We found, however, that in real-world tests, designers found it difficult to begin with a blank slate in a 3D environment. We felt that this might be because the system was underpowered and underconstrained; that is, that it offered too few options and too many degrees of freedom for the user to control. Therefore, we added features to allow designers more ways to create and change designs, and we added constraints on navigation, manipulation, and modification so that users would not be overwhelmed by trying to control so many parameters at once. These changes made the system much more usable, but users still did not produce any significant design concepts completely within our application. Rather, the most successful design sessions using CDS were those in which the user loaded a design concept developed on the desktop, then viewed it, verified it, and made incremental modifications in the VE.

VIRTUAL ZOO EXHIBIT FOR DESIGN EDUCATION

Our current immersive design application provides constraints in a different way than those systems mentioned above. Rather than starting with a complete design system, then constraining object manipulation and modification, we begin with a fully-designed environment, then allow the user to modify aspects of the design and immediately view the results. Thus, instead of focusing our system at the conceptual stages of design, as in CDS, we have emphasized the final stages, when incremental modifications are made to the completed concept. This new system is also quite domain-specific; that is, changes are limited to those which make sense in the domain of habitat design (e.g. trees are always attached to the ground and grow vertically). Finally, our interaction techniques also provide traditional constraints to make them more usable.

The system builds off the work in the Virtual Reality Gorilla Exhibit project [4], an immersive environment designed to teach middle-school children about gorilla behaviors, vocalizations, and social structures. In this application, the student is immersed in a virtual model of the largest gorilla habitat at Zoo Atlanta, and can move throughout the visitors area as well as the habitat itself. Once in the habitat, the user is treated as if she were a juvenile gorilla. Therefore, the other virtual gorillas react to improper behavior by the user, such as entering another animal’s personal space or staring for a long period of time. The virtual gorillas have accurate postures, movements, and vocalizations, and act according to an established dominance hierarchy.

Our application uses the same environment as the Virtual Reality Gorilla Exhibit, an accurate model of the habitat, including the visitors center, topology, moats, rocks, trees, and fallen logs (Figure 1). We have chosen to leave four virtual gorillas in the VE, but they do not move or make sounds. Rather, they provide an important cue as to the scale of the habitat, which is important from a design perspective.

Like its predecessor, the design application is based on the Simple Virtual Environment (SVE) library, a software support library that takes care of the details of tracking, rendering, event-handling, and the like. The system runs on a Silicon Graphics Indigo2 Max Impact, and uses a Virtual Research VR4 head-mounted display (HMD) for visual output. Tracking is performed using a Polhemus Fastrak with three enabled receivers, including a special stylus with a button (see Figure 2). One tracker is used for head position and orientation, while the other two allow us to implement a “pen & tablet” interaction metaphor, described below.

We also used this system to present information about the design of zoo exhibits to students, and found that this type of education, combined with traditional lectures, produced better results on an evaluation than the lecture alone. This study will be described in a separate article.

Figure 1. The Virtual Gorilla Exhibit

Immersive Design in the Virtual Gorilla Exhibit

Our goal in creating an immersive design application geared toward zoo exhibit design was not to implement a general-purpose tool that one could use to design any conceivable animal habitat. This would only be slightly less complicated than a completely general immersive design system, and experience has shown us that such systems are difficult to use and overly complex for casual users. We hoped to provide a "design toolbox" of sorts, which could be used to describe modifications to a few specific parts of the gorilla habitat. The options in the toolbox would be limited enough so that the system could be learned and used quickly, but flexible enough so that interesting designs could be created.

Moreover, we did not aim this application at established environmental architects and designers, since they would not profit from describing changes to an already existing exhibit. Rather, we intended for the system to be used in an educational setting, by students who were inexperienced at environmental design. By using this immersive design system, they could receive valuable insight into the uses of various design elements, and would have an opportunity to put into practice the design philosophies that they were studying. Students could see for themselves the effects of various design choices.

With these goals in mind, we decided to focus on three aspects of zoo exhibit design: terrain and topology, visitor viewpoints, and placement of other visual elements (trees, rocks, and grasses). The system allows modification of any or all of these features while immersed within the virtual exhibit, and users can move freely to any location or point of view.

Shape and contour of the terrain is very important to environmental design. The designer of Zoo Atlanta's gorilla habitat, Jon Coe, champions the philosophy that animals should be above the viewer, and should seem to surround the viewer, as this puts viewers in a subordinate position that predisposes them to learn from the animals and their environment [5]. Thus, the terrain of the gorilla habitat is a large hill that slopes up from the visitors center. The contour of the terrain also provides areas which cannot be seen by the visitors, allowing the gorillas to have some privacy if desired. We considered allowing students to change a portion of the terrain in any way they chose, but this would not ensure that students could produce a topology based on philosophical or even practical considerations. To help guide the students, we instead decided to allow them to choose from eight different terrain models for the exhibit. These models reflect various possible design rationales, such as optimum viewability, optimum animal privacy, viewer subordination, or some compromise between these competing goals.

Design of viewpoints into the habitat is also crucial. The concept of viewer subordination again comes into play, but designers must also consider ways to make viewpoints as naturalistic as possible, such as not allowing visitors to see people at other viewpoints, or surrounding the visitor with foliage so that he feels as if he's peering out from the jungle into a natural landscape. Our system allows users to change two important properties of visitor viewpoints: position and viewing angle. The user controls the position and orientation of two foliage barriers on either side of an outdoor viewpoint, so that the viewing direction and field of view can be specified.

Other visual elements, such as trees and rocks, provide character to an animal habitat and have both practical and aesthetic uses. These objects serve as visual barriers between visitors and animals, or between several animals, providing areas of privacy. Also, the placement of these elements can lead to a more naturalistic setting, enhancing the experience of both the animal and the visitor. Our application allows users to change the location of trees already in the habitat and create new trees, rocks, and tufts of grass at any position in the exhibit.

Interaction Techniques

Previous experience with immersive design and other complex immersive virtual environments has shown that the correct set of interaction techniques is the most crucial aspect of a successful and usable application. For this system, even though we had limited the domain and the options available to the user, we would still require a user interface (UI) that was easy to learn, easy to use, efficient, and effective in allowing users to make the design changes they desired.

To allow the user to control the design of all the features mentioned in the previous section, we needed interaction techniques for navigation, object selection, and object manipulation that were each usable and that integrated seamlessly with one another. This integration was achieved through the use of two common interaction metaphors throughout the system. Users can make many design changes with a *direct manipulation* metaphor. That is, they may manipulate an object, such as a tree, simply by reaching out, grabbing it, moving it to the desired location, and releasing (this is augmented by an arm-lengthening technique which is described below). However, direct manipulation is not always possible or desirable. For example, it may be hard to determine the overall layout of a group of trees while manipulating one directly.

Therefore, we have also made use of a more indirect interaction paradigm called the "pen and tablet" metaphor [6]. The user holds a physical pen in his dominant hand and a tablet in his non-dominant hand (Figure 2). These objects are tracked, and in the virtual environment, visual representations of both of these objects can be seen in the correct positions (see Figure 3). A two-dimensional user interface appears on the surface of the virtual tablet, and the user interacts with this UI using the pen and its button. This metaphor has several advantages for many types of interaction, due to its unobtrusiveness (the tablet may be put aside if not needed), its inherent constraint (the physical surface of the tablet guides the stylus), and its use of two-handed interaction, with the dominant hand working relative to the non-dominant hand. Many interactions can be accomplished using both direct manipulation and the pen and tablet, allowing users to choose the interaction style that is best suited to them and the current situation.

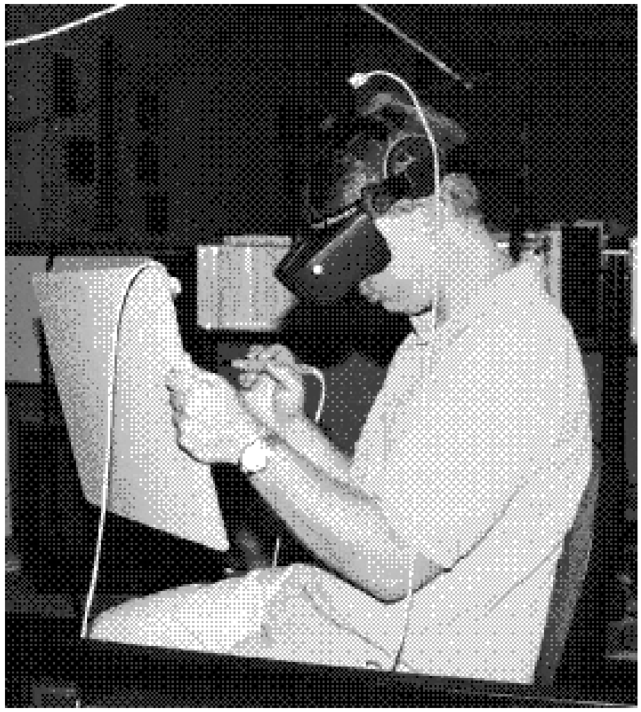


Figure 2. Physical Devices Used in the “Pen & Tablet” Interaction Metaphor

We use the tablet interface for many purposes. First, it provides continuous access to the most common actions. Since the tablet is carried in the user’s hand, she has it available regardless of her position in the virtual environment. Thus, items such as the button used to cycle among the various terrain models are placed on the tablet. Also, the main display of the tablet is a large map of the environment (Figure 3), with icons representing the user as well as some design elements. This helps students understand the overall layout of the space, and their location within the space, analogous to the plan view that architects are accustomed to working with. Finally, various toggle buttons are located on the right side of the tablet, which allow the user to turn on or off the display of several types of information (tree icons, terrain number, viewpoint positions, etc.), so that visual clutter can be reduced.

Usable navigation techniques should allow the user to move around the habitat freely and efficiently, while ensuring that the user does not become lost or disoriented in the 3D space. This is a difficult combination to achieve, since more freedom generally results in higher disorientation, and reducing disorientation depends on constraints, which take away freedom of movement. Our previous studies on the subject of VE travel techniques [7] aided us in combining two techniques which allow complete freedom of movement while also providing aids to reduce disorientation.

The first technique uses the stylus as a pointing device. Users point in the direction in which they wish to move, and hold down the stylus button to travel in that direction with a constant velocity. Users can see a representation of the stylus in the virtual world, so they can visualize the direction they’re pointing. Our previous experiments showed that this technique was accurate and efficient for most user positioning tasks, whether the user was traveling directly to an object or simply wanted to obtain a specific view of the world. The pointing technique decouples the user’s head orientation from the direction of travel, allowing him to move in any direction regardless of the direction of his gaze. One important feature from a design perspective is the ability to fly upwards to get a bird’s eye view of the entire habitat.

Figure 3. User's View of the Virtual Stylus (middle right) and Tablet

Some disorientation is prevented by keeping the user within the habitat using some simple collision detection routines. Users are not allowed to go below the ground or beyond the walls of the surrounding moat. However, flying in three-dimensional space is still difficult for many people, and they may not be able to maintain spatial awareness of their surroundings, causing disorientation.

The second technique, using the pen and tablet metaphor, addresses some of these concerns. The map on the tablet displays a red dot at the user's current position. The user can move by placing the stylus over the red dot, holding down the button, and dragging it to a new location on the map. When the button is released, the user is flown smoothly to the new position in the environment.

This technique has several advantages. First, the map displaying the user's position effectively combats disorientation. If the user feels lost, she can look at the map and find her position relative to some known landmarks. This is true whether the user has been using the pointing technique or the dragging technique. Second, by dragging to a specific location on the map, the user can move quickly to the area of interest, without having to navigate through the actual 3D environment. Third, since the user does not actually change position until he releases the stylus button, he can watch as he travels smoothly from his current location to the new one, and spatial awareness may be increased.

We considered a "view-up" map, which rotates so that the map is constantly aligned with the user's point of view. However, Wickens [8] and others have argued that such a display, while possibly enhancing navigation performance, may reduce retention of the layout of the 3D space. We have instead given users a fixed frame of reference within the ego-centric frame of reference, which forces them to expend some effort in forming mental links between the two types of views, and should cause increased retention of the spatial data.

The user can combine the two navigation techniques in any way. In our experience, most users utilize the pointing technique for exploration and obtaining interesting views of the habitat, and the dragging technique to move quickly to a new area when a design task requires it. The map and the constraints on movement help to keep the user spatially aware.

Object selection techniques are needed for most design actions in our VE. On the tablet, users need to select buttons and icons, and in the habitat, they need to select visual elements for manipulation. We desired a technique that allowed users to select objects at a distance, so that they would not be required to move close to an object to manipulate it. Moving a tree, for example, is much easier when one can step back to obtain a more overall view of the area of manipulation. The selection technique also needed to be cognitively simple, so that users could focus on the task of habitat design, and not on the requirements of the interface.

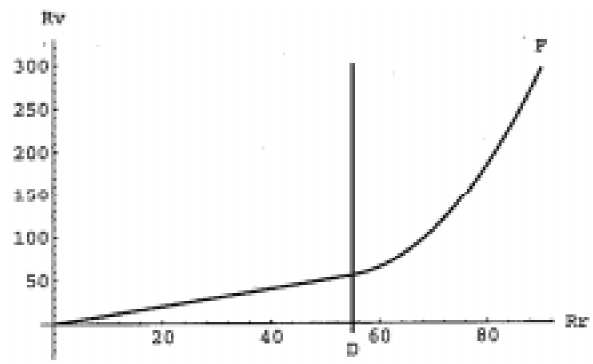


Figure 4. Non-linear Function for Virtual Arm Length Using the Go-Go Technique: Rr = distance of physical hand from body, Rv = distance of virtual hand from body (reproduced from [10])

In a previous study on selection and manipulation techniques for immersive VEs [9], we had found that the ray-casting technique, in which the user points a virtual light ray at an object to select it, was ideal for object selection (although it was not as useful for manipulation). Unfortunately, this technique requires a button to activate the light ray, and our stylus button was already being used for the pointing technique for navigation. We could leave the light ray active at all times, but this might obscure views of the environment. Instead, we chose to use the "Go-Go" technique [10] for object selection. This technique allows the user to stretch his virtual arm well beyond the length of his physical arm, using the mapping function shown in Figure 4. When the physical hand is beyond a certain distance from the user's body, the virtual arm begins to grow at a non-linear rate. Our study showed this technique to be nearly as efficient for object selection as ray-casting, although it may not be as accurate for small objects. Since most of the visual elements we wished to manipulate were fairly large, the Go-Go technique would allow easy object selection from a distance with no change to our navigation techniques. In addition, this technique integrates well with tablet-based interaction. The user holds the tablet close to his body, so that the virtual arm length is the same as the physical arm length when the user is interacting with the tablet. He can then stretch his arm out farther to manipulate objects directly in the environment.

Design Tasks

These basic interaction techniques are used in a variety of ways to effect changes to the design of the virtual habitat. As we have noted, users are allowed to change the terrain, move, create, or delete visual elements, and specify characteristics of the visitor viewpoint.

We have provided eight different terrain models, each reflecting a different combination of design rationales. To cycle between these topologies, users simply click the stylus over a button on the tablet. The terrain then changes immediately, and elements such as the virtual gorillas, rocks, and logs move along with the terrain, so that the user gets accurate and timely feedback on the visual impact of the chosen terrain. Since some of the topologies are similar, the terrain number is displayed on the map as a reference. Since everything necessary for modifying the terrain can be found on the tablet, users can make these changes from any position in the environment.

Design of visual elements in the gorilla habitat can be accomplished using either direct manipulation or the pen and tablet metaphor. As we noted above, users may move trees, rocks, and tufts of grass by simply reaching out using the Go-Go technique until the stylus touches the desired object (the object gives visual feedback when touched), then holding down the stylus button and moving the object in the virtual environment. The user only has to specify two degrees of freedom, since objects are constrained to move along the terrain and objects cannot be rotated. This is not a severe limitation, since these objects all have a natural up/down orientation and are generally symmetric around their vertical axes. Thus, the user is concerned only with placement on the terrain. Most parts of the habitat can be reached from any location, since the Go-Go technique allows users to stretch their virtual arms to many times their normal length.

All of these visual elements can also be arranged on the tablet. As Figure 3 shows, each of the trees, rocks, and tufts of grass is represented by an icon on the map. By selecting and dragging these icons, the user can move the virtual objects quickly to general positions in the habitat. If fine-tuning of their position is needed, the user can then switch back to direct manipulation mode. Dragging is also used to create new objects. A creation palette on the top of the tablet allows users to instantiate new trees, rocks, or tufts of grass, and place them into position in the environment. Again, these tools are always available to the user since they appear on the tablet. Also, the icons on the tablet provide important information about the overall layout of the objects and their positional relationships, similar to the top-down view familiar to architects.

The user can manipulate two characteristics of the outdoor visitor viewpoints: their position and viewing angle. The viewpoints are also represented by icons on the map, and can be clicked on by the user in order to travel there, or dragged to a new location on the periphery of the habitat. In either case, the user is flown smoothly from their current location to the position of the viewpoint, so that the user can experience the view of the user from that location. Once at the viewpoint, the user can manipulate the viewing angle by moving foliage barriers on either side using the Go-Go technique. The barriers can be moved and rotated so that the user can change both the viewing direction and field of view.

Finally, since our interface is modeless, users can combine these design tasks in many useful ways. For example, the user might display both viewpoints and trees on the map to see whether any views might be blocked. She could then move trees by dragging their icons on the map, or travel to the viewpoints and move trees using direct manipulation so that the view is framed exactly as she wants it. The combination of terrain and viewpoint tools is also useful. It may be difficult to see the effects of changing terrain from high above or at ground level within the habitat. The user can instead travel to each of the viewpoints and cycle through the topologies, choosing one that not only fits their design rationale but that also looks appropriate from each of the viewpoints.

USABILITY STUDY

Method

We tested our immersive design application in the context of a class on the Psychology of Environmental Design, taught jointly by the College of Architecture and the Department of Psychology. Students in this class had earlier participated in our study of the educational benefits of a virtual environment, when they used the part of the system that presents information about the design of the exhibit to the user while he is immersed within the gorilla habitat. The class of 24 students was divided into eight project teams, each of which participated in a session using our immersive design tools to modify the existing design of the habitat at Zoo Atlanta.

Teams, consisting of three students each, were instructed to use their knowledge of the philosophy of environmental design and their aesthetic sense to create a unique design using the tools available in the system. After team members completed consent forms and background questionnaires, we gave each team a brief orientation to the system, including the use of the head-mounted display and input devices, and the interaction techniques used to modify the exhibit design. Each member of the team then spent approximately five minutes experimenting with the application, in order to acclimate themselves to the environment and tools. This phase took approximately 30 minutes.

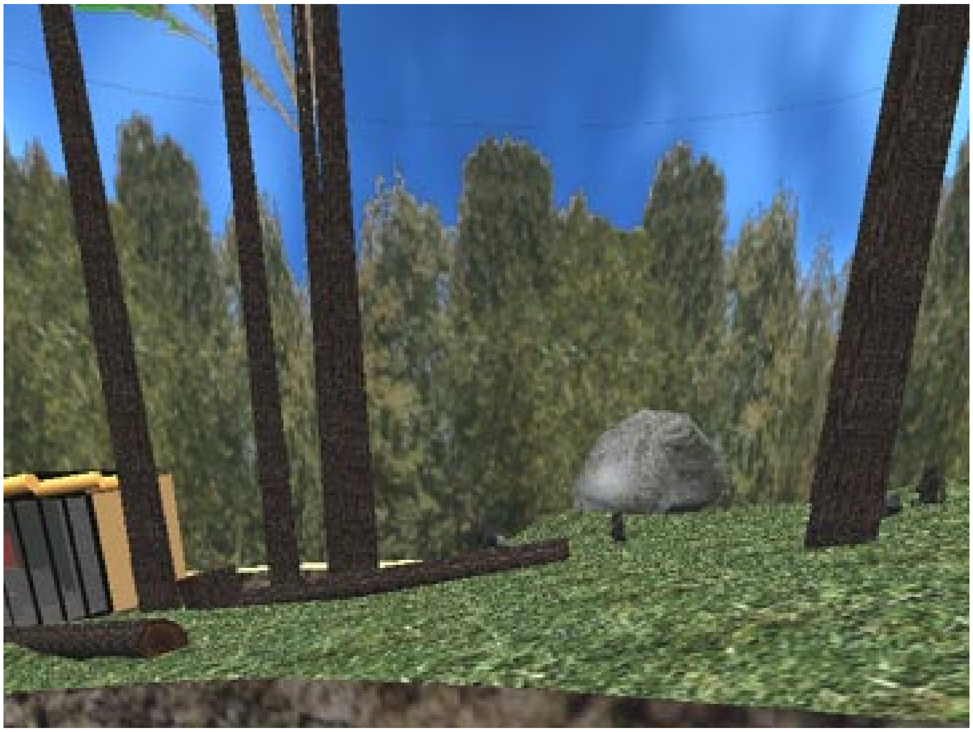
After everyone was comfortable with the system, the team elected a design implementor, who would be responsible for making design modifications using the VE system. The other two members of the team observed a computer monitor showing the implementor’s view of the virtual habitat, and offered suggestions and comments, so that the entire team was involved in the design decisions. The habitat was reset to its original configuration, and the design process began.

During the design phase, we recorded comments made both by the actual user of the system and by other team members. We also noted major errors and difficulties experienced by the implementor for usability purposes. The teams spent between 30 and 60 minutes on their designs.

When the design was complete, we asked the implementor to travel to the location of significant views within the environment, and captured images of these views. The teams later presented their design modifications in class using these images. Finally, we conducted an extensive interview with each team, asking them questions about both the usability of the VE system as well as questions which compared this method of design with more traditional techniques such as drafting or computer-aided design.

Results and Observations

In using our immersive design application, all project teams were able to make significant and unique changes to the design of the existing gorilla habitat, despite the fact that they had less than 15 minutes of instruction, less than 5 minutes of acclimation, and less than an hour of actual usage. In general, we found that the system allowed students to easily visualize the environment and effect desired changes, and that students could adapt to the new paradigm of immersive design to make meaningful modifications.



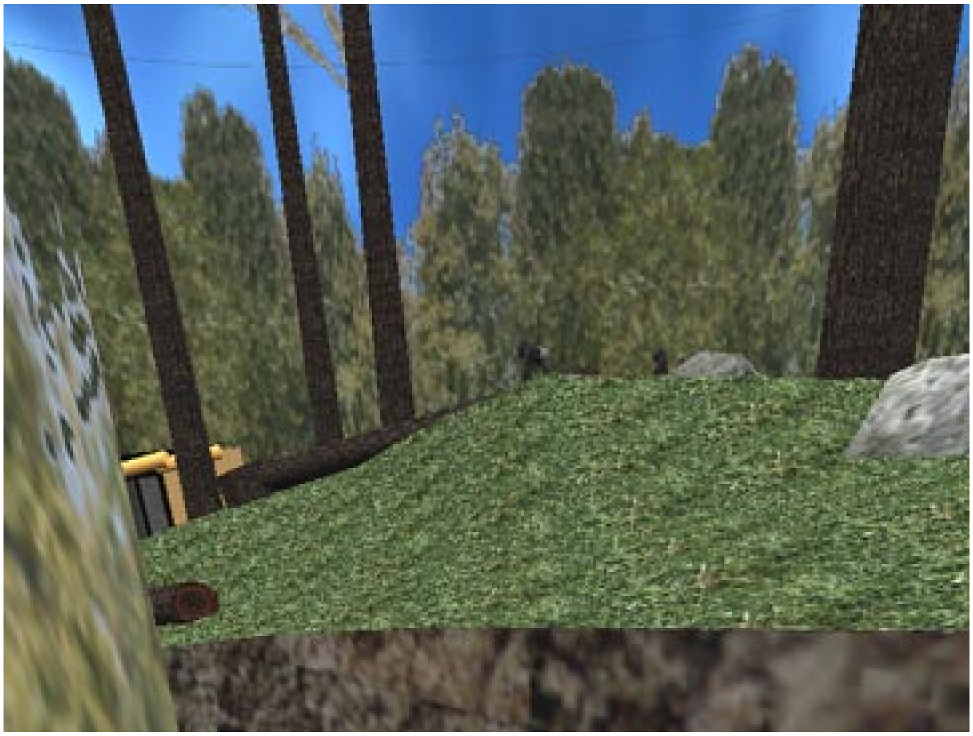


Figure 5. Outdoor viewpoint design before (top) and after (bottom) a group design session.

Figure 5 shows two views from one of the outdoor viewpoints in the gorilla habitat. The first image shows the existing design, while the second image presents an example of student work (more examples can be seen on the Web at http://www.cc.gatech.edu/gvu/people/Phd/Doug.Bowman/arch4751/). Note that the user has changed a viewing angle, moved trees, chosen a new terrain, and created new visual elements to give the habitat a completely different look, while retaining important design philosophies such as viewer subordination, provision of private areas for animals, and blocking man-made structures from view.

One of our primary concerns was the performance of the individual interaction techniques, as well as the intercompatibility between techniques and the overall interaction metaphors. To assess this quantitatively, we asked each group to provide us with usability ratings for a number of system components. The groups were told to consider ease of use, ease of learning, efficiency, and effectiveness in their ratings, and rated features on a scale of 1 to 5, from least usable to most usable. Table 1 shows the results of this survey.

Usability Categories	Category Avg.
tablet: object creation	4.43
tablet: dragging user icon to move	4.21
changing terrain	4.21
moving viewpoints	4.20
moving viewpoint barriers	4.10
tablet: general interaction	3.86
tablet: object manipulation	3.86
user movement with stylus	3.71
go-go object manipulation	3.14
Overall average	3.96

Table 1. Usability ratings (scale of 1 to 5) for key features of the immersive design application

The entries in table 1 reveal some interesting trends. First, notice that when there is a choice of interaction technique (one using the tablet and one using direct, 3D manipulation), the tablet-based technique was preferred. For example, dragging the user icon on the tablet to travel to a new location in the environment was preferable to pointing in the direction of travel using the stylus. This stems from the advantages of the tablet mentioned earlier: it is always available, it has a physical work surface to constrain input, and it requires the user to control only two degrees of freedom. However, the use of the tablet also caused some problems for users, most notably due to orientation differences between the map and the environment. Some users found it difficult and disorienting to drag the user icon in one direction and then move in a different direction, or to drag an object on the tablet to the left and see it moving to the right in the virtual world. Most users were able to adapt to these difficulties by focusing on only one context at a time, and by noting relationships between object positions instead of absolute locations. For example, a user viewing the environment might decide to move a tree to the left. To make it a relative positioning task, he would translate the goal to something like "move the tree closer to the visitors building." Using this goal, either the tablet or direct manipulation methods would work well.

Feedback on the direct manipulation techniques was mixed. Some users found it natural and intuitive to point in the direction they wished to fly, and enjoyed the simplicity and flexibility of this technique. Others became disoriented when they moved in a direction other than the direction of their gaze, and could not point as accurately as they hoped. The Go-Go technique for object manipulation fit the intuition of most users: to move an object one simply reaches towards it. However, there were difficulties due to the size of our environment. In order to allow users to reach most of the environment, the non-linear portion of the Go-Go stretching function (see Figure 4) needed to be quite steep. This meant that when the virtual arm was far from the user's body, a very small movement in or out would result in a large virtual hand movement. This made object selection difficult at large distances. We are currently considering a change to "occlusion selection", in which the user simply covers the object with the virtual hand and presses a button to select it.

A second question we wished to explore was the utility of immersive virtual environments for design purposes. Even if students found the system usable, did they enjoy designing from within the space? How is this paradigm different from drafting or CAD systems, and what are the relative advantages and disadvantages? Simple observation suggests that the students could make the switch to an immersive design environment, and that it offered some capabilities that were not possible with more traditional design methods, while falling short in other areas. To expand on these observations, we asked students about their perceptions of immersive design immediately following their design sessions.

When we asked what made the VE good for design, the most common response was that it offered instant gratification, meaning that the results of a design change were immediately apparent, since they could be seen from within the environment itself. With drafting, designers must project themselves into an imagined 3D world to assess changes. CAD systems may require users to wait for a new 3D rendering to be drawn, which is usually not interactive, but limits the user to a fixed point of view. One user characterized this as the "experiential quality" of the immersive VE, which allows immediate verification and validation of designs. Others commented that the system made it easier to get a sense of scale and perspective due to the fact that they could obtain any view of the environment.

Students also agreed with our assessment that such a tool is more useful for making changes to the details of an existing design than for building a design from scratch. Since the basic structure of the habitat was in place and could not be changed, students could focus on the details that make the design interesting. Several students realized that given the current state of the technology and interaction techniques, that it would be extremely difficult to create a design completely within the VE.

The most common negative response was that the user was immersed at all times within the habitat. Designers commonly work with orthogonal plan, elevation, and section views, and use 3D perspective views as a supplement. The immersive design system supports only the least used of these views: 3D perspective. The students wanted to work on the overall scheme of the design first, and then adjust the details, but our system emphasizes the details, and makes it difficult to obtain an overall view. We intended the tablet to serve as a rough plan view, with the outline of the space, and icons representing the visual elements, but this was apparently not satisfactory to the students. Many of them attempted to create their own more detailed plan view by flying straight up into the sky. The tops of the trees, however, cause views from higher than 50 feet to be obscured.

Students also said that traditional design methods held an advantage in the area of accuracy. For example, in CAD, one can precisely control object size, distance, and positioning, while the immersive system does not take numerical input or produce numerical output of any kind. One student saw this as an advantage, however, as the VE caused him to focus on the “aesthetics and emotion” of the design rather than exact measurements.

Finally, users were not satisfied with the current state of VE technology. For a design application, replicating a real view is extremely important, and our HMD did not pass muster. The most common complaint was that the field of view (FOV) was very low (about 90 degrees horizontal for our HMD). This made it difficult to get an overall sense of the visual impact of the design. Low visual resolution and tracking lag also hinder the use of the system.

CONCLUSIONS AND FUTURE WORK

Overall, we were quite pleased with the results of our study. It showed that an immersive design application can be both useful and usable in a real-world design application. Students were able to use the tools to create unique designs using both practical and philosophical rationales in a short amount of time. The study indicates that immersive design is quite useful for making aesthetic changes to the details of an existing design framework. Users can adapt to this new mode of design from within the space, and receive instant verification of design changes that is not possible using more traditional techniques.

We would like to extend this philosophy of immersive design to other applications in design education, as well as to virtual environments for design professionals. Such tools could be an important new mode of design for any application which has a small, constrained set of operations that can make a significant difference in the visual impact of the design, as was the case with the trees, rocks, grass, terrain, and viewpoints in our virtual gorilla habitat.

We are also continuing our study of interaction techniques for immersive virtual environments. We have shown that the 2D tablet metaphor is quite efficient and usable, but direct manipulation of 3D objects and spaces should also be a part of immersive design. Novel techniques and combinations of techniques for navigation, object selection, and object manipulation are needed to allow designers to make modifications easily and efficiently.

ACKNOWLEDGMENTS

The authors wish to thank the students in the Psychology of Environmental Design course for their participation in our study. We also acknowledge the help and support of Terry Maple, director and CEO of Zoo Atlanta, and the other members of the Virtual Reality Gorilla team: Don Allison, Brian Wills, Kyle Burks, Kristen Lukas, Lori Perkins.

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